



EFFECT OF ALOE VERA EXTRACT AS A GREEN CORROSION INHIBITOR ON IRON METAL IN HYDROCHLORIC ACID (HCl) ENVIRONMENT

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ABSTRACT

Corrosion is a chemical curse that poses a serious problem to both industry and daily life. Iron is widely consumed by various industries due to its attractive mechanical properties and low-cost availability. The Research paper focuses on the anticorrosive behavior of aloe vera extract as an eco-friendly green corrosion inhibitor for iron metal in aggressive acidic environment for a 3-day corrosion test. 2M Hydrochloric acid (HCl) is used to prepare a bit aggressive acidic environment. Inhibiting property of Aloe vera is due to presence of various bioactive compounds such as Polysaccharides, Anthraquinones, Saponins, Amino acids and Phenolic compounds. By gravimetric analysis (weight loss method), the inhibition efficiency of aloe vera extract was determined over a duration of 3 days. Iron strips were immersed in acidic environment at various volumetric concentrations of inhibitor i.e. 20%, 40%, 60%, and 80% respectively. The results shows that the maximum inhibition efficiency of approximately 56.72% is achieved at 80% v/v inhibitor concentration for 24 hrs exposure time.

KEYWORDS: Aloe vera extract, corrosion, Green corrosion inhibitor, 2M HCl, Gravimetric analysis, Inhibition efficiency, Polysaccharides, Anthraquinones, Saponins, Amino acids and Phenolic compounds.

1. INTRODUCTION

1.1 Corrosion An Introduction

Corrosion is a natural but destructive process. Corrosion of iron is most commonly observed as a reddish-brown flaky layer (rust), that forms when iron reacts with water and oxygen. This gradual deterioration weakens the metal, reduces its usefulness, and can eventually lead to complete failure of structures and devices. Chemically, it is an electrochemical interaction of iron with their environment in which iron loses electrons and combines with oxygen and moisture to form iron oxides. This process is particularly rapid in the presence of electrolytes like salts, acids, or pollutants. For example, vehicles in snowy regions often rust more quickly due to the salt used on roads to melt ice.

The impact of corrosion extends beyond just inconvenience. It leads to safety hazards and economic loss in terms of repair, replacement, product losses and

environmental pollution. Weakening of structural materials can cause accidents, such as bridge collapses or pipeline leaks. According to global estimates, the cost of corrosion runs into hundreds of billions of dollars every year due to maintenance, repairs, and replacement of damaged components. This makes it essential to understand how corrosion works and how it can be controlled or prevented.

Several methods have been developed to prevent or slow down the rate of corrosion which include painting or coating the metal to block moisture, galvanizing (coating iron with zinc), using stainless steel or other corrosion-resistant alloys, applying protective chemical treatments and using inhibitors. A corrosion inhibitor is a substance that when added in small concentrations to an environment, effectively reduces the corrosion rate of a metal exposed to that environment.

Corrosion inhibitors can be divided into two broad categories, namely those that enhance the formation of a protective oxide film through an oxidizing effect and those that inhibit corrosion by selectively adsorbing on the metal surface and creating a barrier that prevents access of corrosive agents to the metal surface. Almost all organic molecules containing heteroatoms such as nitrogen, sulphur, phosphorous, and oxygen show significant inhibition efficiency. Despite of these promising findings about possible corrosion inhibitors, most of these substances are not only expensive but also toxic and non-biodegradable, thus causing pollution problems. Hence, these deficiencies have prompted the search for their replacement. Plants are sources of naturally occurring compounds, some with complex

molecular structures and having different chemical, biological and physical properties. Therefore, nowadays the extract of some naturally occurring compounds of plants are mostly used as corrosion inhibitors for metals and alloys because they are environmentally acceptable, cost-effective and have abundant availability.

The causes of corrosion in metals and alloys vary. As summarized in Figure 2, Besides the factors that are shown in Figure 1, corrosion is also influenced by surrounding temperature as well as the presence of certain bacteria species within a biofilm over steel can accelerate an already established corrosion process and promote the conditions to its development.^[1-5]

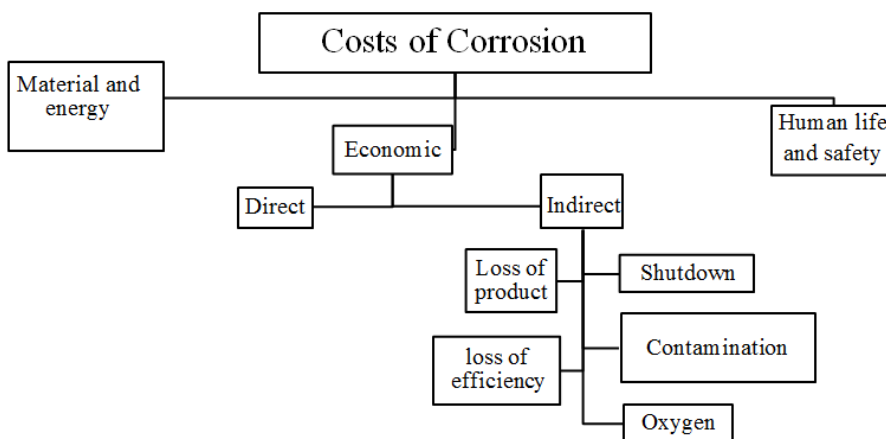


Fig. 1: The breakdown cost of corrosion.^[6]

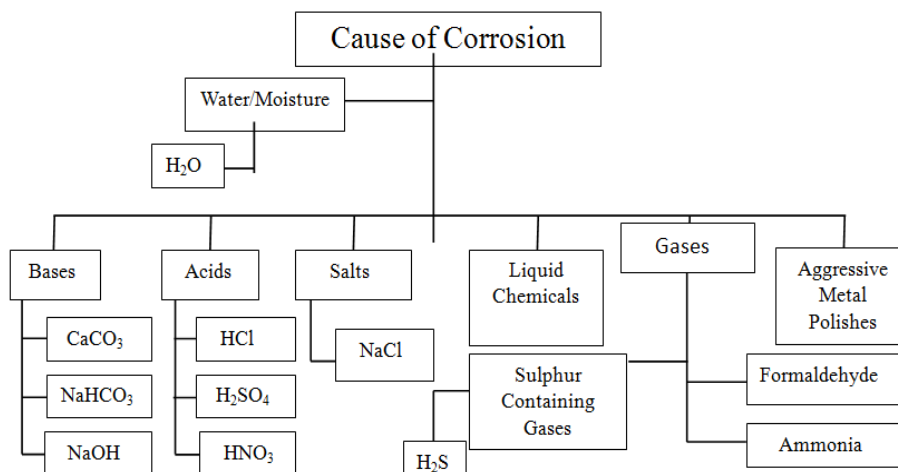


Fig. 2: Causes of corrosion for metal and alloys.^[6]

1.2 General Introduction to Corrosion Inhibitors

Corrosion inhibition is the most excellent approach to avoid destruction of metals and alloys in corrosive media. A corrosion inhibitor is generally defined as a substance which, when added in a small concentration to an environment, can effectively reduce rate of corrosion of metal to its environment. This process started with the adsorption of inhibitors onto the metal surface, forming a protective barrier and interacting with anodic and cathodic reaction sites, thus

decreasing the oxidation or reduction of corrosion reactions.^[6]

1.2.1 Conventional Corrosion Inhibitor

Traditional inorganic corrosion inhibitors (TICIs) and synthetic organic corrosion inhibitors (SOCIs) have been used, due to ease of synthesis and application as well as high effectiveness at relatively low concentration. Generally, TICIs favorably are used in near-neutral medium, whereas SOCIs are used in acidic

conditions. SOCIs containing electronegative functional groups and π -electrons in conjugated double or triple bonds exhibit good inhibitive properties by supplying electrons through π -orbitals. Some chemical families of SOCIs are pyridines, fatty amides, amides, imidazolines and 1,3-azoles and polymers whereas commercial TICIs available are arsenates, phosphates, chromates and di-chromates. Although TICIs and SOCIs exhibited high anticorrosion potential, but due to toxicity which causes environmental pollution during synthesis and application, besides tedious synthetic procedures and high cost of synthesis reagents have been identified as major setbacks. This has encouraged researchers about the development of GCIs.^[7-9]

1.2.2 Green Corrosion Inhibitor

The development of GCIs is basically focused on materials that are renewable, readily available, nontoxic, low cost, eco-friendly processes and environmentally acceptable products. Generally, it can be grouped into two categories, namely, organic green inhibitors (OGCIs) and inorganic green corrosion inhibitors, as shown in Figure 3. Between these two groups, OGCIs can passivate the metal surface uniformly and thus provide the highest possible protection against aggressive corrosion medium. Meanwhile, inorganic inhibitor forms passive layers that are brittle, thus making the metal surface susceptible to local corrosion attacks such as pitting and crevice.^[10-13]

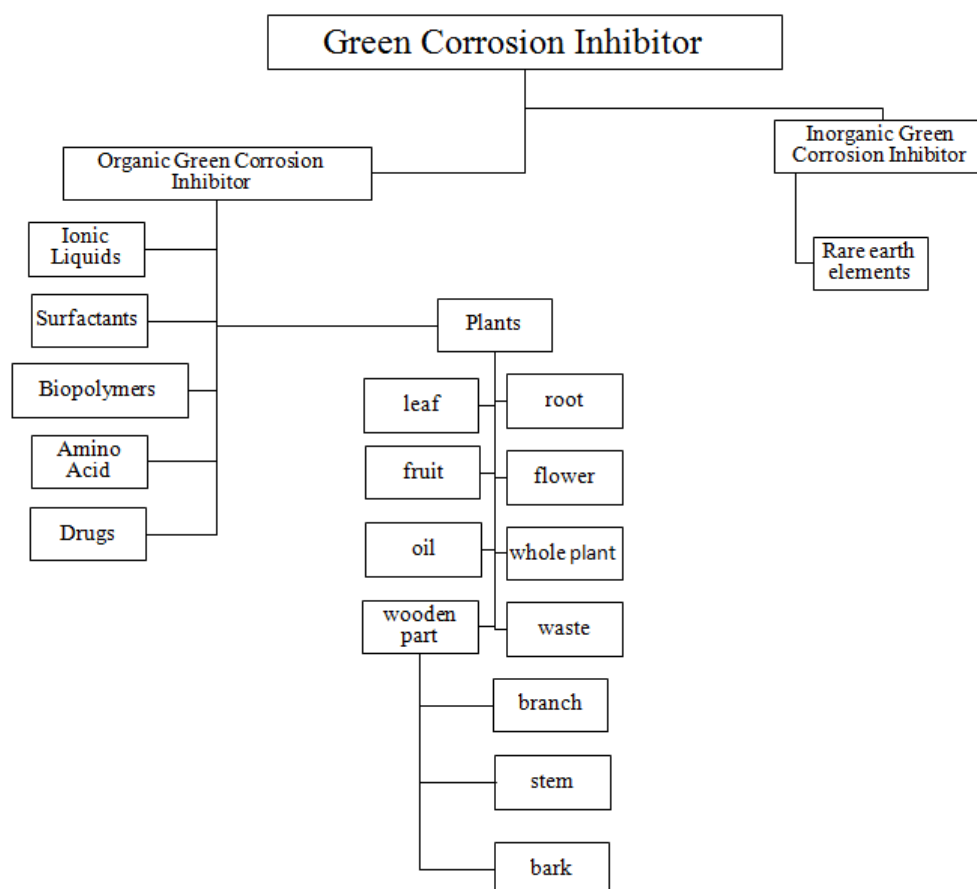


Fig. 3: Group of green corrosion inhibitor.

1.3 Historical Perspective

The first written description of corrosion is found in the works of Plato (427-347 B.C.) in which Plato defined rust as the earthy component separating out of the metal. According to Georgius Agricola, Iron can be protected against this defect by various wrappings, such as red lead, white lead, gypsum, bitumen or tar." Gaius Secundus Pliny also mentioned bitumen, pitch, white lead, and gypsum as protecting iron and bronze against corrosion. The opinion, sometimes expressed today, that modern iron is inferior and more corrosion-prone than old iron, was thus current even in ancient times.^[14]

1.4 Aloe Vera: Chemical Composition

Aloe vera is rich in several organic compounds of high molecular weight, include tannins, saponins, steroids, arabinose, resins, galactose, carbohydrates, polysaccharides, anthraglycosides and anthraquinones. It also contains several biologically active compounds, such as aloin A or barbaloin, aloin B or isobarbaloin, aloe emodin 1 and 2.

Sr. No.	General Name	IUPAC Name	Molecular Formula	%C	%H	%O	%N
1	Aloin A	(10S)-10-Glucopyranosyl-1,8-dihydroxy-3-(hydroxymethyl)-9(10H)-anthracenone	C ₂₁ H ₂₂ O ₉	60.29	5.3	34.41	0
2	Aloin B	(10R)-10-Glucopyranosyl-1,8-dihydroxy-3-(hydroxymethyl)-9(10H)-anthracenone	C ₂₁ H ₂₂ O ₉	60.29	5.3	34.41	0
3	Aloe Emodin 1	4-(7-Butyl-5H-pyrrolo[2,3-b]pyrazin-6-yl)-phenol	C ₁₆ H ₁₇ N ₃ O	71.91	6.41	11.98	9.7
4	Aloe Emodin 2	1,8-Dihydroxy-3-(hydroxymethyl)-9,10-anthraquinone	C ₁₅ H ₁₀ O ₅	66.67	3.73	29.6	0

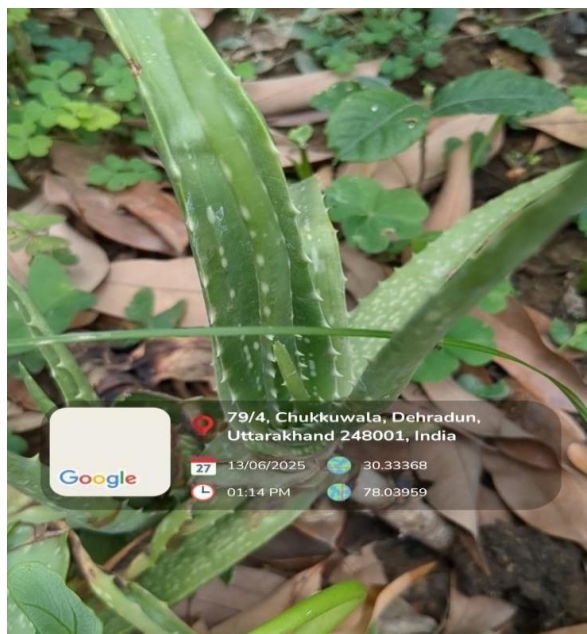


Fig. 4: Picture of Aloe Vera Plant.

The inhibition effect of Aloe vera may be due to the presence of these organic compounds in the extract. Since Aloe vera contains several compounds, synergistic and

antagonistic effects may play an important role in the inhibition efficiency of Aloe vera as an inhibitor.^[1-4]

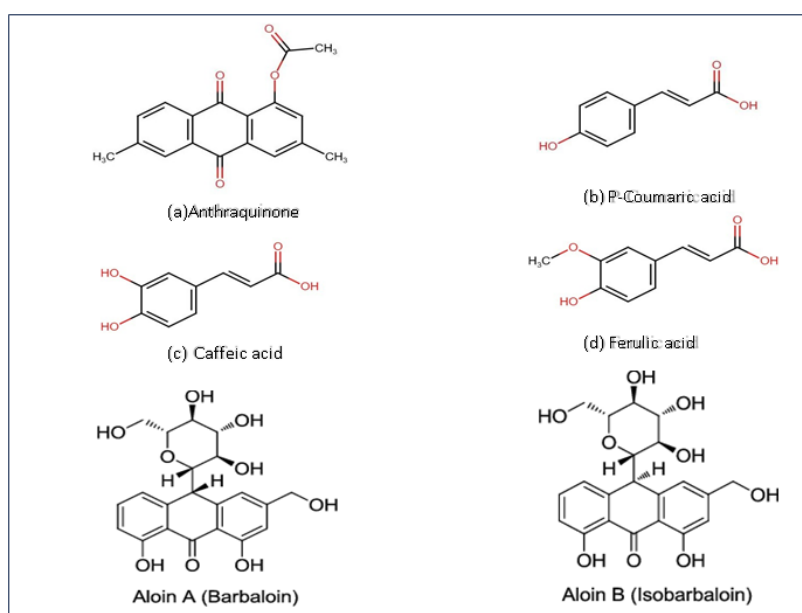


Fig. 5: Bioactive Compounds present in aloe vera.

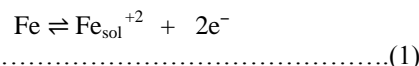
2. REVIEW OF LITERATURE

2.1 Corrosion of Iron and Its Mechanism

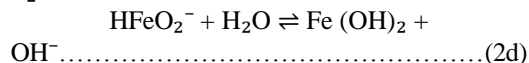
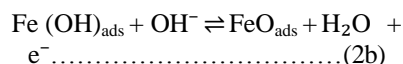
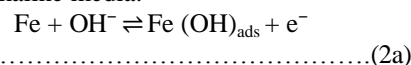
Knowledge of the dissolution kinetics and mechanisms of the iron group metals in the active state is important for corrosion research and practical applications. In the case of the iron group metals the main difficulties arise because of the great number of parameters influencing the kinetics of anodic metal dissolution:

1. The rates depend on the surface structure of the substrate, i.e., the density of steps and kinks on the surface. Electrochemical processes such as selective dissolution of a component from an alloy or absorption of hydrogen into the bulk metal may change the dislocation density. Details of the influence of structure on the dissolution kinetics of metals and alloys are widely unexplored.
2. Further complications arise from the possibility that chemisorbed substances from the electrolyte change the structure of the interphase metal/electrolyte, catalyze or inhibit metal dissolution, and may change the reaction path. Because of these complications, the dissolution kinetics of iron group metals continue to be the subject of many papers. The dissolution behaviour in alkaline or neutral media, even in deaerated or aerated aqueous solutions free of surface-active and complexing substances, is difficult to study because of the easy formation and slow dissolution of protective layers. Also, the influence of surface-active substances on the dissolution kinetics and mechanisms of iron group metals is better known in acid than in neutral or alkaline environments.^[15]

Roiter *et al* (1939) The first kinetic study of the Fe/Fe²⁺ electrode was carried out by Roiter *et al.* in 1939 using large-signal pulse polarization, often called super polarization. The results were interpreted in terms of a rate-determining transfer of Fe (II) in one step influenced by crystallization phenomena:



The stimulation of reaction (1) with increasing pH was first observed by Kabanov *et al.* The kinetic data obtained in alkaline media.



The kinetics in acid solutions were studied by Heusler and Bonhoeffer and Hoar and Hurlen starting in the middle of the 1950s. In the beginning of the 1960s, Bockris and co-workers investigated the kinetics of the Fe/Fe²⁺ electrode in acid solutions using different iron samples. Later, many other authors reinvestigated the kinetics of the Fe/Fe²⁺ system under various experimental conditions, but mainly two different sets of steady-state kinetic data were obtained, fitting either the Heusler mechanism or the Bockris mechanism.^[16]

Iron Dissolution in Acid Solution

Fundamental studies on the iron dissolution kinetics were carried out in acid aqueous solutions free of oxygen and surface-active or complexing substances.

Acid solutions are usually used for pickling in order to remove rust from their surface. Results indicate that metal dissolves most rapidly in pure sulfuric acid solution, somewhat more slowly in pure hydrochloric acid and slowest of all in pure phosphoric acid. The dissolution of iron in H₂SO₄ is slowed down by halide ions.

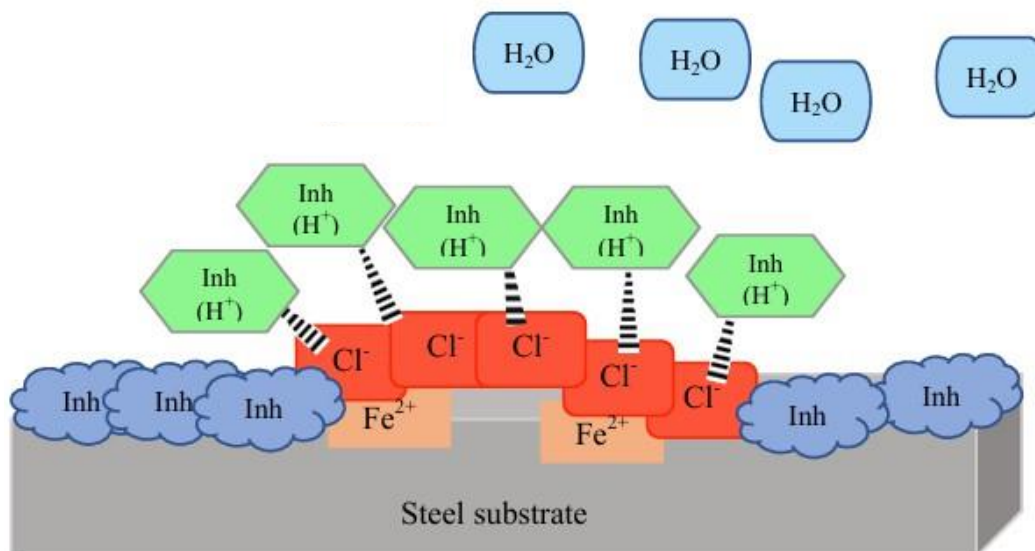
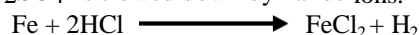


Fig. 6: Physical adsorption scheme of protonated inhibitor in HCl medium on the metal surface.

Abiola and James (2009): Corrosion, particularly in acidic environments, is a major industrial concern, especially for metals like zinc, which are commonly used in galvanization and battery production. The research employed the weight loss technique to evaluate the performance of Aloe vera as a green inhibitor. The work of Abiola and James contributes valuable insight into the field of green corrosion inhibitors, confirming that Aloe vera extract can effectively inhibit zinc corrosion in acidic media. This supports the broader potential of phytochemicals in sustainable corrosion management strategies.

Pallav Shah and Shruti Agarwal (2014): The paper titled "Aloe-Vera: A Green Corrosion Inhibitor" by Pallav Shah and Shruti Agarwal from Nirma Institute of Technology, Nirma University, discusses the use of Aloe Vera as a corrosion inhibitor in industrial applications. The study focuses on comparing the effectiveness of Aloe Vera in protecting galvanized iron against corrosion in two different acidic solutions, HCl and H₂SO₄.^[17]

Mashooque *et al.* (2021): The study by Mashooque *et al.* (2021) investigates Aloe Vera extract as a sustainable inhibitor for medium carbon steel in a sulphuric acid environment. Using FTIR, the presence of functional groups responsible for inhibition was confirmed.^[18]

M. Srivastava (2021): Srivastava (2021) contributes to this growing field by investigating the use of *Amaranthus* extract, commonly known as Pigweed, as a green corrosion inhibitor for mild steel in 4N hydrochloric acid. The study explores the electrochemical behavior of the metal surface in the presence of the inhibitor, focusing on critical parameters such as corrosion current density and anodic and cathodic polarization behaviors.^[19]

2.2 Inhibition mechanism of Green Corrosion Inhibitors

In general, the adsorption mechanism of GCIs on metal substrate can be classified as physisorption, chemisorption or combination of these two adsorptions also called as mixed-type adsorption inhibitor (Faisal *et al.*, 2018). Mixed inhibitors provide the highest protection because they affect both cathodic and anodic reactions (Brycki *et al.*, 2018).

Hanani *et al.* (2019) have proposed physical adsorption mechanism scheme based on the nature of corrosion inhibitor as shown in Figure 12 (Hanani *et al.*, 2019). They have reported that the extract contains multiple bonds, aromatic rings and heteroatoms which can be protonated easily in acidic medium. The inhibitor's protonation leads to positively charged inhibitor species that can be adsorbed on the positively charged steel surface via chloride ions and form interconnecting bridges known as electrostatic interaction.

The effect of corrosive medium on inhibition mechanism also needs to be considered. Oguzie *et al.* (2008) reported

that different adsorption mechanisms are obtained when different corrosive mediums are used. They described that the *Hibiscus sabdariffa* extract showed chemisorption in 1 M H₂SO₄ and showed physisorption in 2M HCl (Oguzie, 2008). The corrosion inhibition of GCIs via physisorption or chemisorption option is dependent on the corrosive agents attack the metal surface to protect the metal substrate's surface.

2.3 Green Corrosion Inhibitors: A Sustainable Approach

Traditional inhibitors are expensive, toxic and have negative impacts on the environment. That is why environmentally friendly, cost-effective, highly effective corrosion inhibitors have attracted the attention of researchers.^[20] So, the concept of green corrosion inhibitors has gained popularity. Plant extracts offer significant economic, safety, and environmental advantages eventually over synthetic/inorganic inhibitors. Studies have shown that the parts of plants used as raw materials for the development of corrosion-inhibitive extracts do not normally come with extra costs. Therefore, that component of cost is an added advantage as far as the overall cost is concerned in comparison to inorganic inhibitors.^[21-27]

Based on research results, plant extracts are extremely reliable and cheap metal corrosion inhibitors, identifying the bioactive elements responsible for their inhibitive property remains major research. The future of corrosion inhibition using plant-based extract, therefore, lies in the ability of researchers to isolate the active ingredients to optimize the use of the corrosion inhibition process on mild steel particularly.

Regarding humans and environmental safety, Verma *et al.* recommend plant-based extracts amongst other organic inhibitors because of the abundance of complex phytochemicals contained in each plant extract which acts as adsorption sites at metal/inhibitor interfaces as viable metallic corrosion inhibitors for different biological and industrial applications. Another strong reason for their preference for environmentally friendly corrosion inhibitors is that, despite their complex nature, they are easily soluble in polar electrolytes due to their association with high peripheral functionalities in the form of polar functional groups. This will, undoubtedly, encourage researchers who are currently working hard to increase their production efforts, as well as to attract more investments in corrosion prevention using plant-based extracts to promote the combat against environmental pollution caused using inorganic inhibitors.

Several studies have explored the effectiveness of plant extracts and other natural compounds as corrosion inhibitors. In addition to natural extracts, the development of green chemistry has introduced ionic liquids as a new class of corrosion inhibitors. Furthermore, vapor-phase corrosion inhibitors (VPIs) are

gaining industrial attention due to their ease of application and efficiency. Overall, the literature supports the growing utility and importance of green corrosion inhibitors, with ongoing research aimed at understanding their mechanisms, optimizing their use, and expanding their applications across various industries.^[28]

2.4 Aloe Vera: Potential as a corrosion Inhibitor

Aloe barbadensis Miller ie. Aloe vera was chosen in this study because apart from having many benefits in various health areas, it is also rich in antioxidants.^[29-32] This antioxidant property is critical in preventing corrosion because it forms complex compounds and protects metal surfaces.^[33] According to several studies, Aloe vera have the potential to act as corrosion inhibitors in acids.^[34-39] However, studies and evaluations of the active substances from Aloe vera extract as inhibitors in the seawater environment are still relatively rare; thus, they should be investigated further. Therefore, this investigation aimed to analyse Aloe vera extract's performance in developing eco- friendly corrosion inhibitors that are environmentally and easy to implement in seawater environments.

The infrared spectrum reveals that Aloe vera extract possesses many functional groups, enhancing active chemicals' ability to associate with metal surfaces by adsorption. The main absorption peak at 3252.58 cm^{-1} in Aloe vera extract suggests the existence of OH or NH

bonds, indicating the existence of alcohol compounds or amide group chemicals. At a wavelength of 2925.40 cm^{-1} , another peak indicates the stretching of C-H bonds, suggesting the presence of hydrocarbon group molecules. Furthermore, the signal peak observed at 1024.97 cm^{-1} indicates the existence of amine chemicals. The signal observed at 1583.06 cm^{-1} predicts the presence of the aromatic compound, namely the stretching of the C=O bond. Furthermore, several peaks at 1397.68 cm^{-1} , 1320.92 cm^{-1} , and 1256.11 cm^{-1} suggest the potential existence of C-N and C-O functional groups. The presence of active substances in the functional group of Aloe vera extract is believed to have a role in inhibiting corrosion.

3. METHODOLOGY

3.1 Materials Used

The materials selected for this study are chosen to evaluate the corrosion inhibition efficiency of natural Aloe Vera extract on iron specimens under controlled conditions. The primary materials used include:

Iron specimen

- Iron commercially available as Mild-Steel used for this study.
- Composition of Mild steel used in experiment (wt.%)

Elements	Iron (Fe)	Phosphorus (P)	Manganese (Mn)	Silicon (Si)	Sulphur (S)	Carbon (C)
Composition	98.7	0.0020	0.581	0.488	0.0030	0.387

Aloe Vera Extract

- Source: Fresh Aloe Vera leaves are collected from the garden of 79/4 Chukkuwala Dehradun 248001 India.
- Concentration Variants: The Aloe Vera extract is used in different volumetric concentrations 20%, 40%, 60%, and 80% in corrosive medium (i.e. 2 M HCl) as required.
- Purpose: The Aloe Vera extract acts as a green, biodegradable corrosion inhibitor rich in phytochemicals which contribute to adsorption on the metal surface and reduction of corrosion.

Corrosive Medium

- An acidic environment is created using hydrochloric acid (HCl) of concentration 2 M to accelerate the corrosion process and test the inhibition efficiency of Aloe Vera under aggressive conditions.

Supporting Materials and Equipment-

- Beakers, conical flasks, and test tubes for immersion experiments.
- Weighing balance (model-OHAUS PAG 213) for gravimetric analysis.
- Thermometer for maintaining temperature control during experiments.

- Stopwatch or timer to ensure consistent immersion periods (e.g., 24, 48, 72 hours).
- Desiccator for specimen storage post-treatment to prevent additional oxidation.
- Combination of iron specimens and Aloe Vera extract, along with standard corrosion testing setups

3.2 Preparation of Aloe Vera Extract

The Aloe Vera leaves were thoroughly washed under running water to remove any dust, dirt, or surface contaminants. The cleaned leaves were carefully peeled off using a clean stainless-steel knife. The inner fleshy, transparent gel was exposed and manually extracted by pressing and squeezing the leaf portions by hand. The extraction was carried out at room temperature (approximately 29°C) to preserve the natural bioactive compounds. The resulting gel-like, pulpy extract was collected into a clean beaker. To obtain a clear and refined solution, the collected Aloe Vera gel was passed through a fine muslin cloth or filter paper, effectively removing fibrous residues and impurities. The filtered Aloe Vera extract was subjected to analysis using UV-vis spectrophotometric method to confirm the presence of functional groups associated with phenolic compounds and other active constituents responsible for corrosion inhibition.

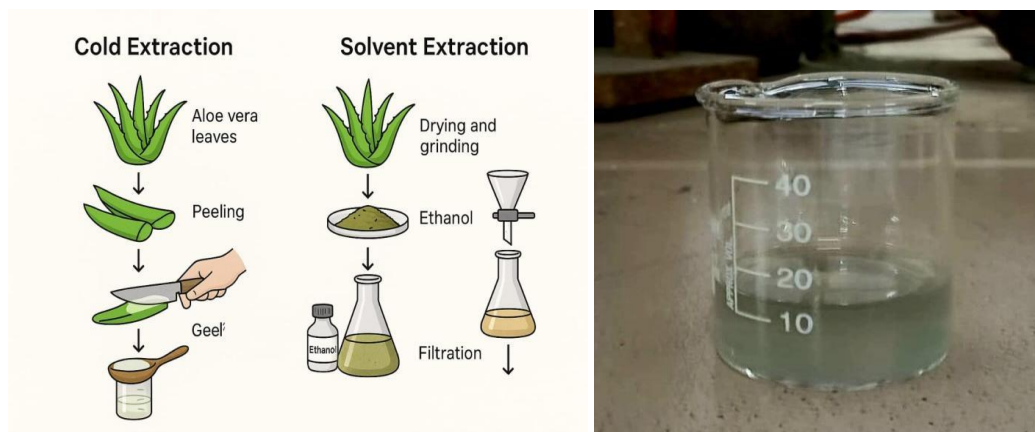


Fig. 7: Aloe Vera Extract.

3.3 Preparation of Iron Specimens

The iron specimens used in this study were prepared in the form of rectangular plates with dimensions of 4 cm × 2.5 cm × 0.3 cm. Initially, each iron plate was mechanically polished using emery papers of varying grades to obtain a smooth and uniform surface, free from rust, scale, or other surface irregularities. After polishing,

the specimens were carefully washed with distilled water to remove loose particles, then degreased using acetone to eliminate any oil, grease, or organic contaminants that might influence corrosion behavior. Finally, the specimens were dried completely under ambient conditions to prevent any premature oxidation before immersion.

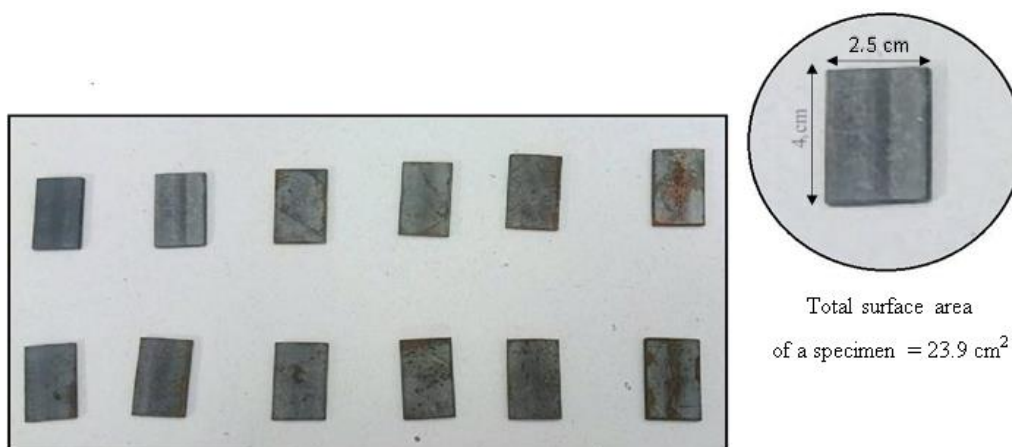


Fig. 8: Iron specimens (Dimensions, 4cm × 2.5cm × 0.3 cm).

3.4 Gravimetric Analysis

3.4.1 Weight Loss Measurements

Weight loss analysis was carried out to study the effect of Aloe Vera plant extract as an eco-friendly corrosion inhibitor in a 2M HCl environment on mild steel. The test was conducted at room temperature 30°C. Samples were immersed in test solution of aloe vera extract at various volumetric concentrations 20%, 40%, 60%, and 80% for 24 h, 48 h, and 72 h. Weight loss measurement at different concentrations and immersion times were calculated using Eq: 01, 02, and 03. Table 2 shows the results of weight loss, corrosion rate (CR), and obtained inhibition efficiency values (IE%). The obtained data shows that weight loss of medium carbon steel samples significantly decreases with an increase in inhibitor concentration at different exposure times.

Table 1,2 and 3 indicates the inhibition efficiency (IE %) of Aloe vera plant extract as a function of adsorption inhibitor – as the concentration of the inhibitor is

increasing results thus substantial increase in surface adsorption of anthraquinone molecules which increase inhibition efficiency of Aloe vera plant extract. Moreover, the maximum efficiency was obtained at 80% (v/v) approximately 56.72% for 24h, 48h, 72h exposure time. It is reported that inhibitors are absorbed on the metallic surface and provide a barrier between metal and the environment.^[19]

$$\Delta W = W_i - W_f \quad (1)$$

Corrosion rates (CR) were determined using weight loss data in given equation (2).

$$\text{Corrosion rate} = \frac{\text{Weight loss (g)} \times K}{\text{Alloy density (g cm}^{-3}) \times \text{Exposed area (A)} \times \text{Exposure time (hr)}}$$

$$\text{Corrosion Rate} = \Delta W / A t \quad (2)$$

Whereas ΔW is the weight loss of the coupon in mg, A indicates the surface area of the specimen, and t determines the time of each experiment in hours. From the obtained corrosion rate at different concentrations of

inhibitor, the inhibition efficiency (IE) of the inhibitor was determined by using equation (3).

CR_{blank} (absence of inhibitor) and CR_{inh} (presence of inhibitor) represent the corrosion rates.^[3]

$$IE(\%) = \frac{CR_{blank} - CR_{inh}}{CR_{blank}} \times 100 \tag{3}$$

3.5 Calculation of Corrosion rate and Inhibition Efficiency

Day 1 (24 hrs)

Table 1: Calculation of corrosion rate at day 01.

Time (in days)	Inhibitor concentration (in %v/v)	Initial Weight(g)	Final Weight (g)	Weight loss (g)	Corrosion Rate (g/day)	Inhibition efficiency (IE%)
1	00	25.000	24.199	0.801	0.0335	-
1	20	25.000	24.447	0.553	0.0231	31.04%
1	40	25.000	24.527	0.473	0.0198	40.90%
1	60	25.000	24.618	0.382	0.0160	52.24%
1	80	25.000	24.653	0.347	0.0145	56.72%

Day 02 (48 hrs)

Table 2: Calculation of corrosion rate at day 02.

Time (in days)	Inhibitor concentration (in %)	Initial Weight(g)	Final Weight (g)	Weight loss (g)	Corrosion Rate (g/day)	Inhibition efficiency (IE%)
2	00	25.000	23.154	1.846	0.0386	-
2	20	25.000	23.321	1.679	0.0351	9.07%
2	40	25.000	23.468	1.532	0.0321	16.84%
2	60	25.000	23.979	1.021	0.0214	44.56%
2	80	25.000	24.047	0.953	0.0199	48.45%

Day 03 (72 hrs)

Table 3: Calculation of corrosion rate at day 03.

Time (in days)	Inhibitor concentration (in %)	Initial Weight(g)	Final Weight (g)	Weight loss (g)	Corrosion Rate (g/day)	Inhibition efficiency (IE%)
3	00	25.000	21.866	3.134	0.0437	-
3	20	25.000	22.411	2.589	0.0361	17.38%
3	40	25.000	22.727	2.273	0.0317	27.47%
3	60	25.000	23.036	1.964	0.0274	37.30%
3	80	25.000	23.454	1.546	0.0216	50.57%

4. RESULTS AND DISCUSSION

4.1 Weight Loss Results

Present graphs show the weight loss of iron metal with and without the inhibitor in the duration of 3 days:

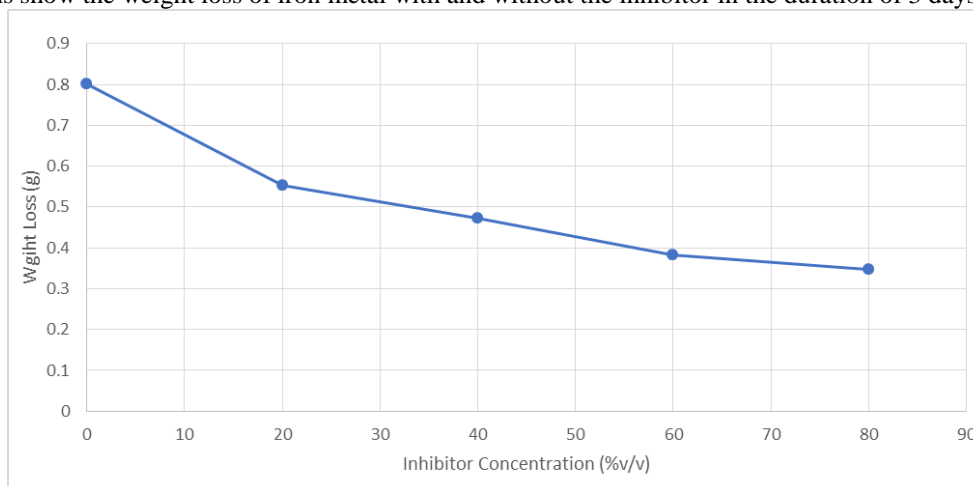


Fig. 9: Weight loss results of Day 01.

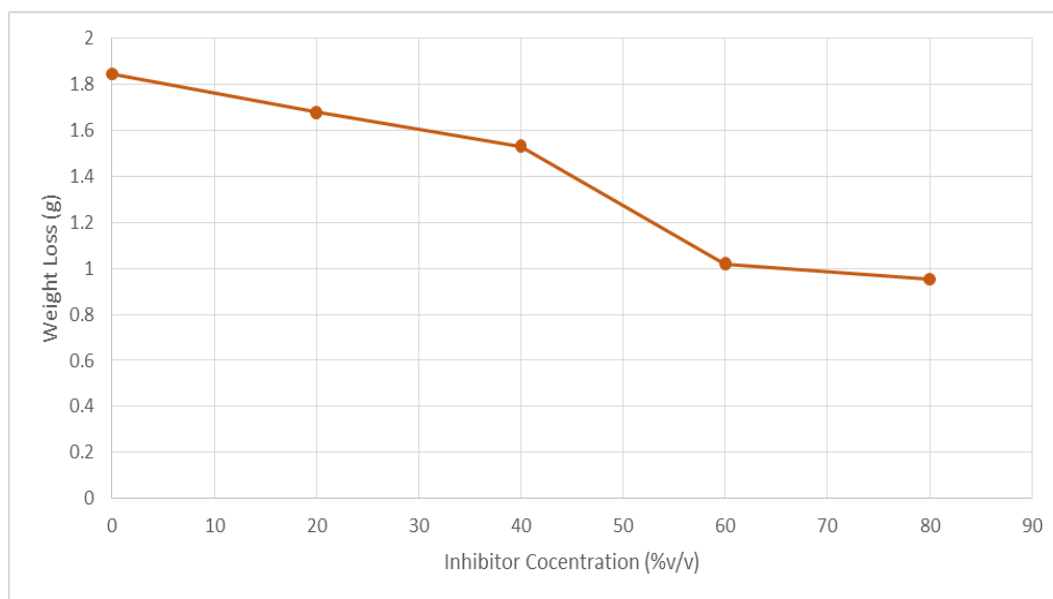


Fig. 10: Weight loss results of Day 02.

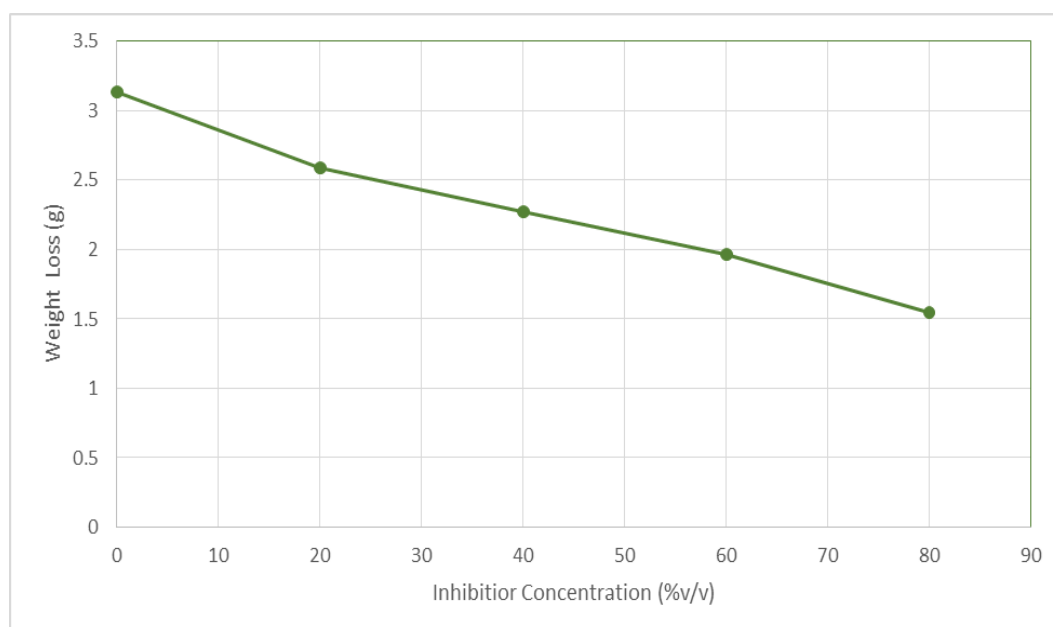


Fig. 11: Weight loss results of Day 03.

On Day 1 (24 hours), the weight loss in the blank sample (without any inhibitor) was 0.801 g. With increasing concentrations of Aloe Vera extract, the weight loss progressively decreased. At 20% concentration, the loss reduced to 0.553 g, followed by 0.473 g at 40%, 0.382 g at 60%, and the lowest, 0.347 g, at 80%. This trend suggests that even within a short exposure period, the Aloe Vera extract began to slow down the corrosion process, as reflected by the lower metal loss.

On Day 2 (48 hours), the blank sample showed a higher weight loss of 1.846 g due to the extended exposure. As with Day 1, increasing Aloe Vera concentrations reduced the weight loss to 1.679 g, 1.532 g, 1.021 g, and 0.953 g at 20%, 40%, 60%, and 80% respectively.

This consistent reduction indicates that the protective effect of the extract continued and became more apparent with both time and concentration.

On Day 3 (72 hours), the trend continued. The blank specimen experienced the highest weight loss of all three days at 3.134 g. In samples with Aloe Vera extract, the weight loss reduced to 2.589 g, 2.273 g, 1.964 g, and 1.546 g for the 20%, 40%, 60%, and 80% concentrations, respectively. The data clearly shows that the inhibitor effectively reduced the degradation of the iron metal over time.

4.2 Effect of Aloe Vera Concentration

Present graphs show the inhibition efficiency of aloe vera inhibitor in the duration of 3 days:

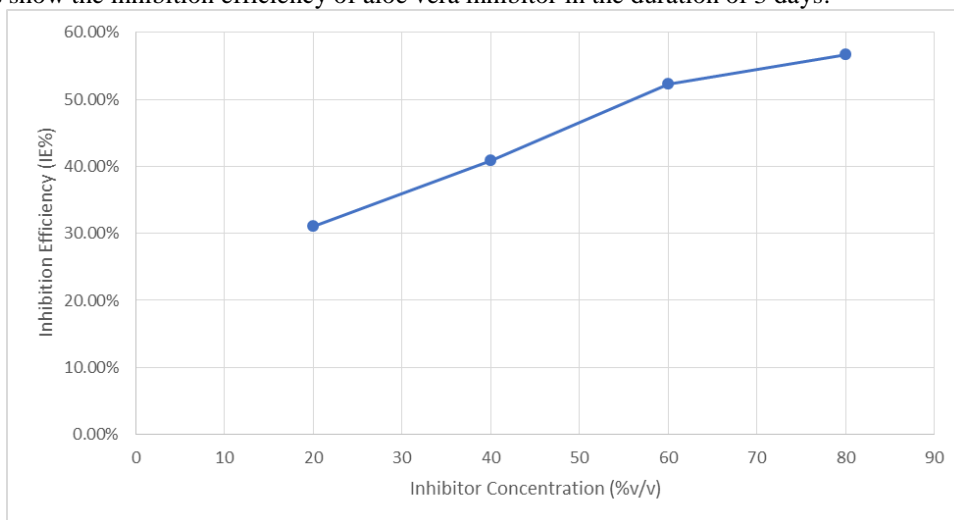


Fig. 12: Inhibition efficiency results of Day 01.

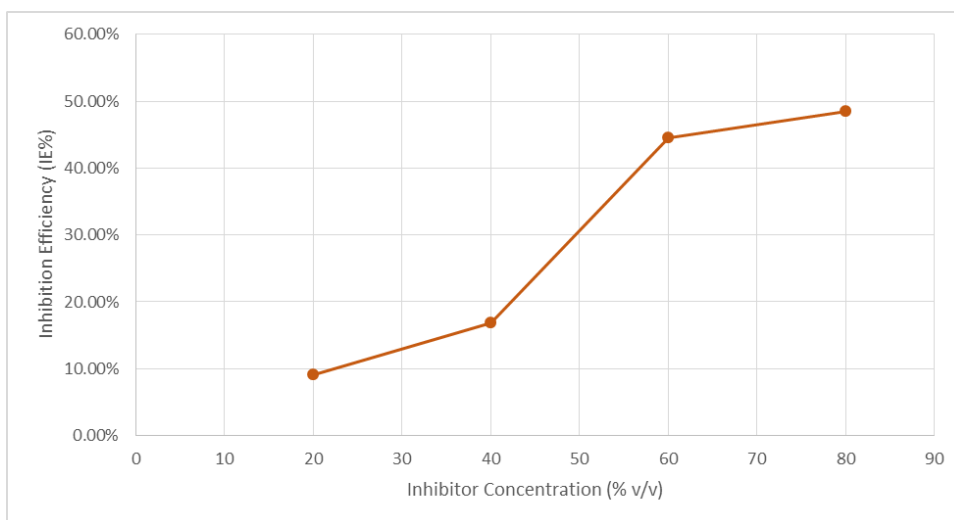


Fig. 13: Inhibition efficiency results of Day 02.

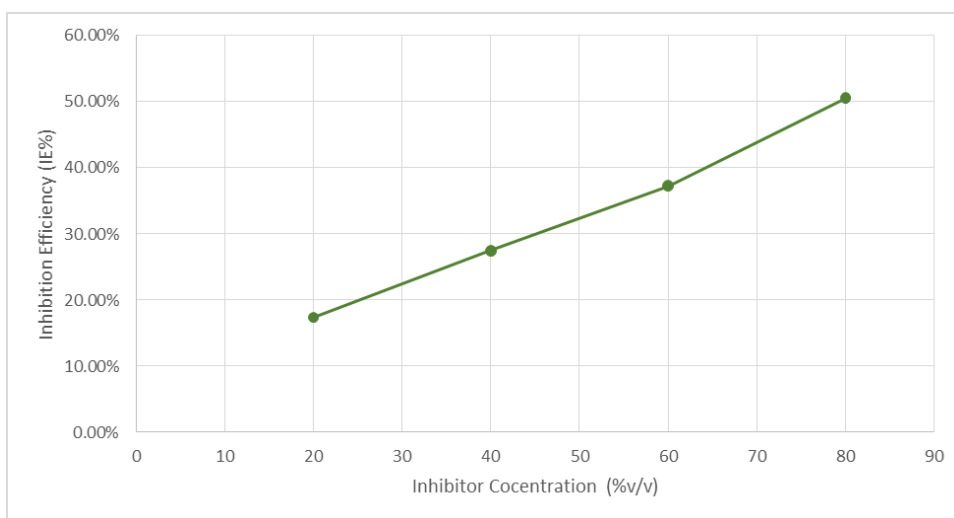


Fig. 14: Inhibition efficiency results of Day 03.

On Day 1, a clear trend of decreasing corrosion rate was observed with increasing inhibitor concentration. At 20%

inhibitor concentration, the corrosion rate dropped to 0.0231 g/cm²/day, and at 80%, it further decreased to

0.0145 g/cm²/day. The inhibition efficiency rose from 31.04% at 20% to 56.72% at 80%, showing a strong protective effect even within just one day of exposure.

On Day 2, after 48 hours of immersion, the blank sample showed an increased corrosion rate of 0.0386 g/cm²/day, as expected due to the extended exposure. However, Aloe Vera extract continued to exhibit effective inhibition. The inhibition efficiency increased from 9.07% at the lowest inhibitor level to 48.45% at the highest. While slightly lower than Day 1's efficiency at 20%, the trend remained consistent, affirming the inhibitor's continued performance over time.

On Day 3, with 72 hours of exposure, the blank specimen exhibited the highest corrosion rate among all three days, measured at 0.0437 g/cm²/day. The Aloe Vera inhibitor maintained its protective role. The inhibition efficiency again improved with concentration, starting from 17.38% at 20% and reaching 50.57% at 80%. This shows that while absolute corrosion increased over time due to longer exposure, Aloe Vera extract consistently reduced corrosion across all durations tested.

4.3 Influence of Temperature and Immersion Time

The test was conducted at room temperature 30°C. Samples were immersed in test solution of aloe vera extract at various volumetric concentrations 20%, 40%, 60%, and 80% for 24 h, 48 h, and 72 h. Weight loss measurement at different concentrations and immersion times were calculated using Eq: 01, 02, and 03. Table 1, 2 and 3 shows the results of weight loss, corrosion rate (CR), and obtained inhibition efficiency values (IE%). The obtained data shows that weight loss of medium carbon steel samples significantly decreases with an increase in inhibitor concentration at different exposure times. Generally, as temperature increased, the corrosion rate also increased, which is typical for acid corrosion of metals due to higher kinetic energy and faster electrochemical reactions. The inhibition efficiency of Aloe vera extract slightly decreased at elevated temperatures, indicating **physisorption** as the dominant inhibition mechanism. Physisorbed molecules are less stable at higher temperatures, leading to desorption and reduced protective effect. If inhibition efficiency increases with temperature, this suggests **chemisorption**, which involves stronger chemical bonding with the metal surface.

5. CONCLUSION

5.1 Overall result of weight loss

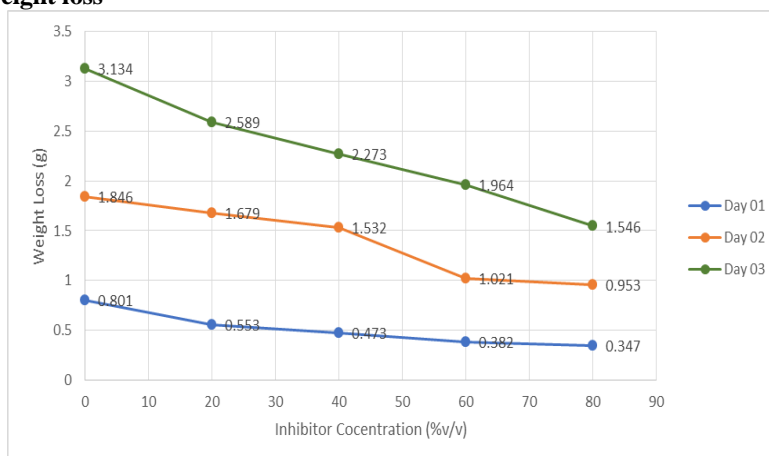


Fig. 15: Overall Result of Weight Loss.

5.2 Overall Result of Inhibition Efficiency

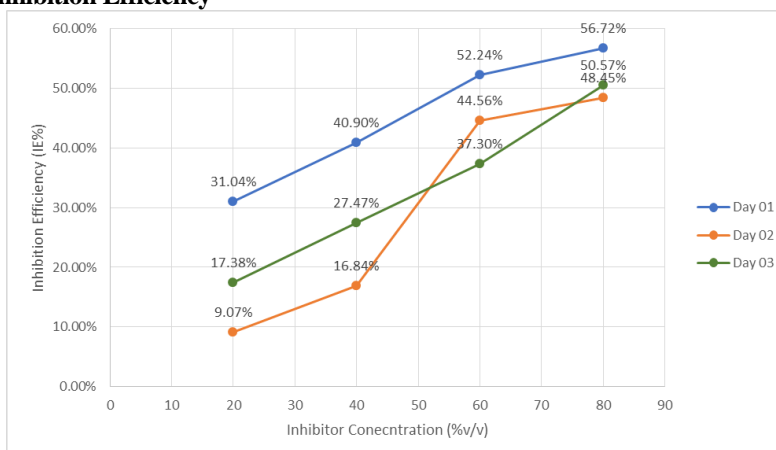


Fig. 16: Overall Result of Inhibition Efficiency.

The weight loss experiments demonstrated a clear inhibitory effect of Aloe Vera extract on the corrosion of iron in 2M HCl. Across three immersion periods (24, 48, and 72 hours), the weight loss of iron specimens significantly decreased with the increasing concentration of Aloe Vera extract. On Day 1, the maximum inhibition efficiency recorded was 56.72% at 80% inhibitor concentration, reducing the weight loss from 0.801 g (blank) to 0.347 g. This protective effect persisted over longer immersion times, with 48-hour and 72-hour tests showing inhibition efficiencies of 48.45% and 50.57%, respectively, at the highest concentration. The reduction in corrosion rate confirms that Aloe Vera extract effectively adsorbs onto the iron surface, forming a protective layer that limits the interaction between the metal and the aggressive HCl environment. The data also revealed a concentration-dependent behavior, where higher extract content resulted in lower metal loss and higher inhibition efficiencies. However, prolonged exposure (72 hours) led to an overall increase in weight loss due to extended acid attack, though Aloe Vera extract still provided substantial protection. These findings validate the potential of Aloe Vera as an eco-friendly and cost-effective corrosion inhibitor for iron in acidic conditions.

CONCLUSIONS

1. Aloe Vera is an Effective Green Inhibitor

The study confirms that Aloe vera extract can significantly reduce the corrosion rate of iron in a 2M HCl acidic medium. Its efficiency increases with higher concentrations, reaching up to ~56.72% at 80% extract concentration.

2. Inhibition Mechanism is Predominantly Physical Adsorption (Physisorption)

The inhibition appears to result mainly from physisorption, where phytochemicals in Aloe vera adsorb onto the iron surface to form a protective film. This barrier limits the access of corrosive agents to the metal.

3. Performance Improves with Concentration, but Affected by Time and Temperature

Aloe vera's inhibition efficiency improves with both increasing concentration and exposure time. However, higher temperatures reduce efficiency, confirming that the adsorption is weak and reversible, typical of physical adsorption.

4. Bioactive Compounds Play a Critical Role

The corrosion-inhibiting property is attributed to the presence of organic compounds in Aloe vera, such as phenolics, anthraquinones, and amino acids. These compounds contain functional groups (like OH, NH, and C=O) and π -electron systems that promote adsorption onto the metal surface.

5. Aloe Vera is a Viable Eco-Friendly Alternative to Synthetic Inhibitors

Compared to conventional inhibitors, which are toxic

and expensive, Aloe vera offers a biodegradable, non-toxic, and readily available green alternative. Its application aligns with global environmental and regulatory trends.

6. Gravimetric Analysis Validates Inhibitory Performance

The weight loss method used in the study provided clear and quantifiable evidence of Aloe vera's corrosion-inhibiting performance over time and varying conditions.

7. Further Research is Needed

While the results are promising, future studies should focus on isolating the specific active components responsible for inhibition, evaluating long-term effects, and testing in more complex industrial environments (e.g., seawater, elevated pressures).

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